WHITE PAPER

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Providing Sustainable Climate Control for the Archives Research Center at the University of Illinois

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Introduction

In 2014, the University of Illinois Library in partnership with the University of Illinois Facilities and Services Construction Management Division and the Image Permanence Institute received $300,000 in support of a *Sustaining Cultural Heritage Collections* implementation grant to upgrade the existing climate control system and install fire suppression for the Archives Research Center (ARC). This project sought to improve the HVAC system operation and energy efficiency as well as to provide a sound preservation environment for our valuable archival holdings held therein. This environmentally sustainable system was designed to operate with better control of temperature and relative humidity, be optimized for maximized energy efficiency, and include protection against fire. This implementation grant served as a critical step towards improving the preservation of one of the most valuable and unique aggregate collections held by the University of Illinois Libraries. Before this grant, the materials were stored in a suboptimal environment with no available fire suppression putting valuable collections at immediate risk. Improvements in the care of our special collections and the facilities that hold them continue to be an ongoing priority for the University Library. Preservation and access to our special collections remains a top priority in our current and past strategic plans, both at an institutional level and within the preservation program.

Previous Conditions

The vault storage areas within the ARC consist of a three floor (11,314 sq. ft.) space constructed in 1921 for use in research on fruits and vegetable crop storage, and use of insecticides and fungicides. The vaults were originally designed to maintain consistent temperatures of 0, -20, and -40°F on the basement, first and second levels, respectively, for long-term crop storage. To hold these temperatures, the vaults were constructed in the interior of the building with foot-thick cork insulated walls along the perimeters with minimal penetrations (1-2 doors on each floor) in order to maximize temperature control. As the agricultural program's needs for this space waned, it was targeted as an advantageous location for archival storage due to its construction and layout. In the mid-1990s, a facility retrofit was undertaken in preparation for the establishment of the ARC at the Horticultural Field Lab, which involved the erection of shelving, and upgrades to the mechanical systems serving the vault spaces. The original ammonia gas refrigeration system was removed from the cold room/vault areas and replaced with a residential quality heating, ventilating, and air conditioning (HVAC) system and ductwork to service the three vault spaces, which did provide the capacity for limited dehumidification and humidification. However, installation of the ductwork to service the space required removal of some of the insulation between vault floors and ceilings, as well as some penetrations in the vault walls. Although this system was installed to provide a better preservation environment for archival storage, it proved to be incapable of delivering the environment that is essential to the long-term preservation of the University's historical collections of papers, motion picture film, audio and video recordings, and music instruments stored therein. The upgrades at that time also did not incorporate fire suppression into the storage areas, which was crucial for the protection of our collections. However, the Library felt that, due to the construction, the vault spaces still provided an excellent match for long-term archival storage if the environment and fire protection issues could be corrected. Construction of a comparably secure, well-insulated, and spacious facility would have been exceedingly costly, whereas re-utilizing this existing structure and making necessary upgrades would result in an archival storage facility capable of long-term storage of our valuable collections.

Since 2006, the Library's Preservation Unit has been actively tracking environmental conditions within the ARC collection storage areas including the monitoring of temperature and relative humidity as well as undertaking integrated pest management (IPM) activities. Five PEM2 dataloggers have been located within the vault storage areas and the data, collected monthly, has been processed through the Image Permanence Institute's (IPI) web application *e-ClimateNotebook*. See Appendix I for *e-ClimateNotebook* output from 2006 to 2012.

The temperature variation (see *Figure One Appendix A*) from the previous HVAC unit was fairly acceptable (with annual variations generally between 65 and 72 °F, and an average temperature of 69 °F, but with undesirable spikes going as low as 52 and as high as 89 °F), however the system was incapable of operating efficiently or sustainably at the cooler temperatures suggested for long-term paper storage (below 65 °F) since the system was designed for human comfort, not archival storage. The relative humidity (RH) control, or veritable lack thereof, was an even more significant problem with annual fluctuations between 14% and 95% RH (see *Figure Two*, again showing the three floor vault areas). While gradual annual shifts of relative humidity are acceptable for paper storage, the extremely low RH during the winter months, with the system's inability to humidify the air, was extremely damaging to the paper, audiovisual, and especially the historic music instrument collections over time, as was the extreme annual shifts, even if gradual, of 81% RH. These non-ideal conditions were the best that the 1990s era system was capable of, and this only with constant maintenance and oversight (variations in RH have been increasing since 2011 even with proactive maintenance). Since the system was nearing 20 years old, the reliability of the HVAC system was anticipated to continue to decrease each year, making its timely replacement critical.

By analyzing the prior storage environment using the Image Permanence Institute's preservation metrics, it was estimated that the time weighted preservation index (TWPI) for the vault storage environment was 46-49 (depending on the floor) for the five years of monitoring between 2009 and 2013. The TWPI is helpful as a quantitative comparison of the preservation quality of different storage locations or environments and is a tool that integrates the temperature and relative humidity values as they change over time into a single estimate of the cumulative effects of the environment on the rate of chemical decay[1]. For reference, a TWPI of 75 or higher is considered "good", with increasing preservation benefits as the number increases. At Illinois, storage spaces for comparable collections in the University Library system have TWPIs of 97-300 (recorded in the Rare Book and Manuscript Library and our high-density storage facility). Since materials housed in the ARC are not appropriate for either of these two physical locations, we intended to increase the preservation capacity of our current location in the ARC.

Although the vault storage areas are equipped with smoke detectors, no fire suppression system had been installed in the space; one was initially planned during the mid-1990s HVAC retrofit, but cancelled due to budget overages. Due to the high value of the collections and the high concentration of combustible materials such as papers and wooden music instruments, it was also

[1] See: https://www.imagepermanenceinstitute.org/environmental/research/preservation-metrics for a full explanation of the use of the TWPI as a preservation metric.

viewed as critical for the safety of the collection to install a fire suppression system. A wet-pipe system was preferred in the ARC. Additionally, it was desired that the fire detection system would be upgraded to include a VESDA fire detection system for additional security.

Previous Grants

In 2010, The University of Illinois was awarded a Sustaining Cultural Heritage Collections Planning Grant to investigate sustainable options for energy efficient preservation storage in the ARC. The project team was composed of people with three areas of expertise: library/archives experts, campus planning and sustainability experts, and contracted engineers and project planners. Library/archives experts addressed preservation, access and library-specific facilities issues. Overarching preservation needs were addressed by Jennifer Hain Teper (Head of Preservation Services). Specific preservation and access needs for paper and instrument collections were addressed by the respective archivists, William Maher (University Archivist and Head, ARC) and Scott Schwartz (Sousa Archivist and Head, Sousa Archive and Center for American Music). Library facilities issues were addressed by Jeffrey Schrader (Assistant Dean of Libraries for Facilities). The campus planning experts were members of the campus' Facilities and Services (F&S) Department, who oversee and manage all facilities construction and renovation projects. Campus planning personnel for this project included Ted Christy (an architect with significant library project experience) and John Prince (an HVAC engineer with significant library project experience). In addition, F&S contracted engineering services included the campus sustainability coordinator (Morgan Johnston) to effect as much energy conservation in the project as possible while still maintaining an acceptable environment. The project involved all necessary campus members in order to ensure satisfactory production of project drawings and specifications through the schematic design phase of an HVAC remodel. The production of this end product was monitored, analyzed and confirmed with the project team throughout the timeframe of the grant to ensure a high-quality outcome that met the needs of long-term archival storage as well as considered long-term energy efficiency and sustainability.

Project Activities

The grant award of $300,000 ($50,000 less than originally requested) was announced September 5, 2013. Although we had anticipated the grant would start immediately upon award, this was delayed by the project's need to undergo a formal review in accord with Section 106 of the National Historic Preservation Act, in collaboration with NEH Sr. Program Officer Joel Wurl. This review, which started in late September 2013 was successfully passed in April 2014. Grant funds were not awarded until after this approval had taken place. However, the University of Illinois did start the first articulated step of the process for selecting and awarding contracts for professional mechanical engineering services. This process, which did not involve the use of grant funds, was begun while the Section 106 review was underway in order to keep the project on schedule as much as possible. The firm of TRC Worldwide[2] was selected and put under contract in October 2013. Also during this time, the Image Permanence Institute consultant, Jeremy Linden, was brought into the project to review the project's progress to Schematic Design and to make any recommendations for changes to the scope of the project. Mr. Linden offered advice to improve energy efficiency as well as long-term

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[2] (http://www.trcww.com/our_contact/our_usa_offices.html)

preservation by transitioning from a desiccant wheel to a more traditional chilled water dehumidification system, as well as redesigning the system to work one, centralized air handler and an ancillary humidification system for the music instrument storage (which required higher year-round humidity) as opposed to the initially proposed separate AHUs. As a result of Mr. Linden's recommendations, the process of value engineering of the project was discussed with the project team and TRC Worldwide starting on November 11, 2013. This new, value engineered approach was formally accepted and a kickoff meeting incorporating these changes took place on December 12, 2013. Due to the scope change, however, the Schematic Design phase needed to be repeated to incorporate these significant design changes. The new Schematic Design phase reached 100% review on February 7, 2014 and 100% Design Development review on April 1, 2014. However, the budget associated with this DD proposal was significantly higher than originally budgeted. Additional funds needed to be secured to accomplish the established goals of the grant while incorporating design simplifications to bring the total project budget increase to $135,845 (all covered by the University of Illinois). Therefore, significant collaboration between the Library staff (including preservation, archives and facilities staff), campus Facilities and Services, and the mechanical engineering firm and their consultants) took place before reaching a 50% review of Construction Documents, which did not occur until October 15, 2014. This re-evaluation of the project was very valuable, but resulted in an additional delay in the project timeline.

The second year involved the continued project construction design and approval and the start of construction. 95% Construction Documents were submitted and approved in mid-December of 2014, and construction bids were opened in January 2015. The bid process closed in February and the lowest bids came in more than $200,000 *over* the consultant estimates. By May 2015, the University Library identified funds to cover most of the budget overage, while also re-thinking the construction of the new music instrument vault to economize construction costs while not compromising the quality and size of the storage vault. A general contractor was selected and signed onto the project in June, and a pre-construction kick-off meeting was held by mid-July 2015. Weekly construction meetings were held thereafter with all stakeholders and progress began on the removal of shelving, electrical updates, HVAC upgrades and the installation of fire suppression. An additional glitch (an insufficiently sized water line from the street to the building) was identified in September 2015 to serve the new fire suppression system. The project scope was altered to include connecting an 8" line through property and into the basement of the building. This project adjustment cost an additional $155,000. Funds were identified through a request to the University of Illinois' Provosts Office in October of 2015 and, blessedly, the project continued on schedule from that time.

In the third year of the grant project, construction continued with relatively few complications and the system came online over the summer of 2016. The grant team (Library Facilities staff, Library preservation staff, IPI staff, and campus facilities and services representatives) met July 12-14 to review the system installation and expected operations, and placed the data loggers specified in the grant proposal into all concerned collection spaces and the mechanicals. Since mid-July 2016 until the end of the grant period (and beyond) we have been logging the system output and working with IPI, campus facilities and services, and the design engineers to increase reliability and efficiency of the system. During this time, there were some issues with unexpected condensation within and around the system that were determined to be due to poor design by the contracted mechanical engineering firm. Design and construction of an environmentally controlled enclosure for the attic mechanicals was completed in October 2017. This is due in response to the fact that in the fall of 2016, condensation issues were noted on the exterior of the air handing unit. Later in 2016 and early

2017, issues with the system pipes freezing up were also experienced. After discussion with the planning engineers, it was quickly determined that an enclosure should have been planned around the AHU (located in an unconditioned attic space) – and plans and funds were put in place to build a conditioned space for the AHU to operate more consistently year-round. Final balancing of the system was completed in May 2017 and the system has been operating largely as expected since that time. The warranty period for the equipment (in which no deviations from the planned installation set points were possible) ran until August 2017. After the expiration of the warranty period, more flexibility with experimentation with changing seasonal set points for reduced energy consumption have been possible.

The fourth and final year of grant project was a no-cost extension to allow us to run the now operational HVAC unit and test its capacities, responses, and energy consumption with input from IPI, the results of which are included in their final report, included as Appendix I.
To coordinate with that flexibility, the final visit from IPI was scheduled for September 13 and 14, 2017. During that visit, IPI consultants Kelly Krish and Christopher Cameron (Jeremy Linden left the IPI in August of 2017) discovered a significant impact on heat load in the conditioned spaces from the peripheral heated hallways in the cooler months. Project staff have continued to monitor and experiment with modifying set points, alarms, and possible increases in percentages of outside air intake to bring winter temperatures down. However, the full depression of temperature during the winter months may not be recognized due to this effect. It is important to note, however, that insofar as energy consumption is concerned, the increased temperature is not being held mechanically by the system, so energy savings are still gained during winter months.

Project Accomplishments

Despite significant hurdles in insufficient planning and design almost entirely by the mechanical engineering firm, the system is now running smoothly and efficiently, though winter temperatures have not been as low as originally proposed due to impact of heat load from ancillary spaces.

Mechanical set points are now established at:

	Archival Storage Vault (rooms 4, 107, 201)	**Music Instrument Vault (room 108a)**
Summer Set Point	60 °F ., 55 % RH	60 °F ., 50% RH
Summer Alarms	High temp: 65 °F . Low Temp: 55 °F . High humidity: 60% RH Low humidity: 50%	High temp alarm: 65 °F . Low Temp alarm: 55 °F . High humidity alarm: 55% RH Low humidity alarm: 45% RH
Winter Set Points	50 °F ., 30 % RH	50 °F ., 45 % RH
Winter Alarms	High temp: 55 °F . Low Temp: 45 °F . High humidity: 35 % RH Low humidity: 25 % RH	High temp alarm: 55 °F . Low Temp alarm: 45 °F . High humidity alarm: 50% RH Low humidity alarm: 40% RH

The graphs providing in *Appendix 1* show current data collected by the PEM dataloggers installed in the various vault spaces since the new HVAC system came online in August 2016 to the present. These show a dramatic increase in the control over the humidity in the renovated spaces, though there have been some hiccups getting the system to run consistently. In addition, all spaces are now equipped with fire suppression systems.

Evaluation

Overall, the project is viewed as a success. The long-term preservation of irreplaceable humanities collection has been dramatically improved as a result of this project. Previous to the HVAC remodel, the reliability of both temperature and, more significantly, humidity have been greatly improved. The rate of chemical deterioration of our paper and audiovisual collections stored in the vault have been dramatically decreased by the stabilization of humidity fluctuations (previously annual fluctuations ranged from 14% in the winter to as high as 95% in the summer). This is illustrated in the chart, below, showing increases in the time weighted preservation index (TWPI) of greater than 50%. Our goal at the outset would have been to have this decrease in deterioration be even higher due to more greatly reduced temperatures in the winter through passive cooling, but as explained above, that has not been found to be possible without additional mechanical intervention. The physical stress of these fluctuations has also been remediated for our historical music instrument collection by moving these materials to a separate, conditioned space with higher and more stable relative humidity than the paper vaults, offering ideal storage for delicate composite materials.

Space	**TWPI before renovation**	**Overall TWPI after renovation**
Room 4 (basement vault space)	47	73
Room 107 (1st floor vault space)	47	71
Room 201 (2nd floor vault space)	47	71
Room 108 (music instrument vault)	N/A	73

Lessons Learned

Sadly, one of the most important lessons that we learned in this project is to never assume that professional contractors are asking all the right questions, or considering all the necessary factors to work towards the desired result (see multiple budget overages, above). Our University Archivist, Bill Maher, offered the following in our presentation on the project to the Society of American Archivists in August 2017, many of which stand true for all library and archive professionals involved in this project:

"Never assume:

- That experts and specialists will think of the basics
- That architects and contractors will provide correct backups or that occupant-accessible monitors and controls will be part of the system
- That contractors and workers will protect your materials from dust, dirt, or over-spray

- That one contractor or one campus trade will talk to the others
- That once finished, there will be little need for monitoring or aggressive pursuit of preventative maintenance and repairs
- No question is too 'dumb' to ask"

Additionally, we learned that despite our best efforts, environmental targets are not always achievable and to remain flexible and accept that significantly better is just fine even if it falls a bit short of the anticipated goal.

Appendices

Appendix One: eClimateNotebook Environmental Records, Past and Present

Appendix Two: Images

Appendix Three: IPI Final Report

Appendix One: eClimateNotebook Environmental Records, Past and Present

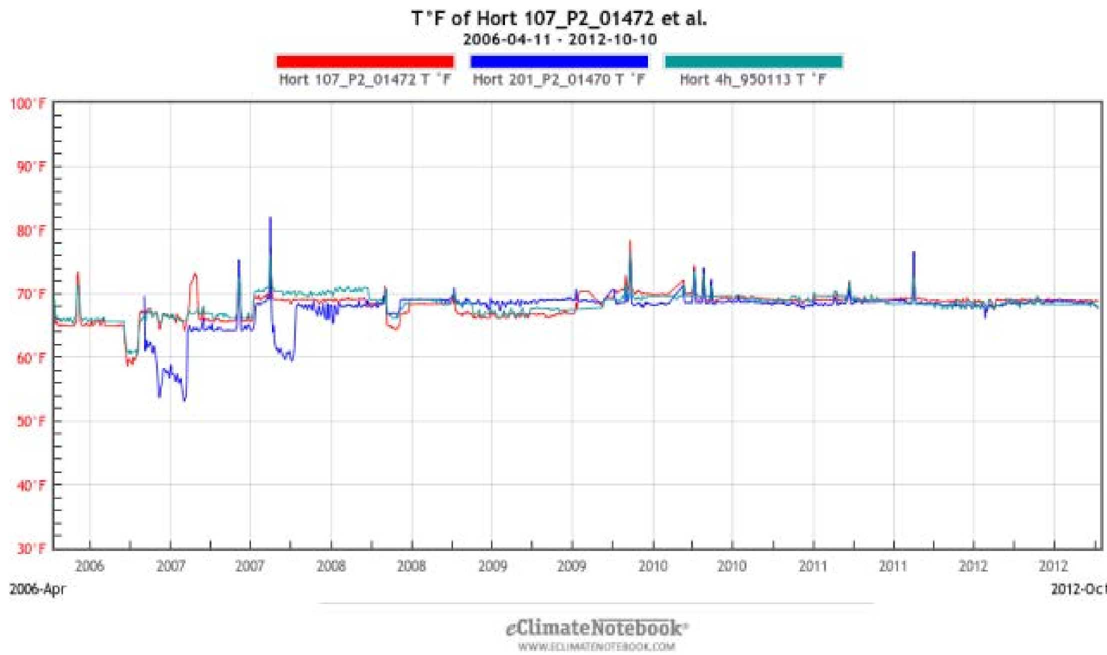


Figure One: Temperature measurements for three floors of the vault from 2006-2012

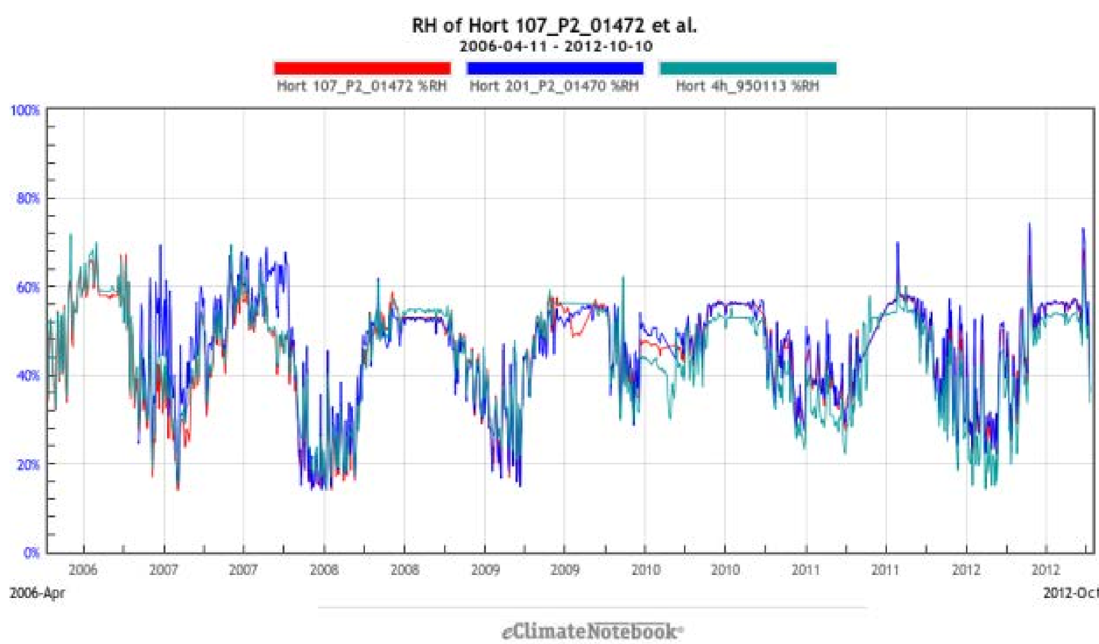


Figure Two: Relative humidity measurements from 2006-2012

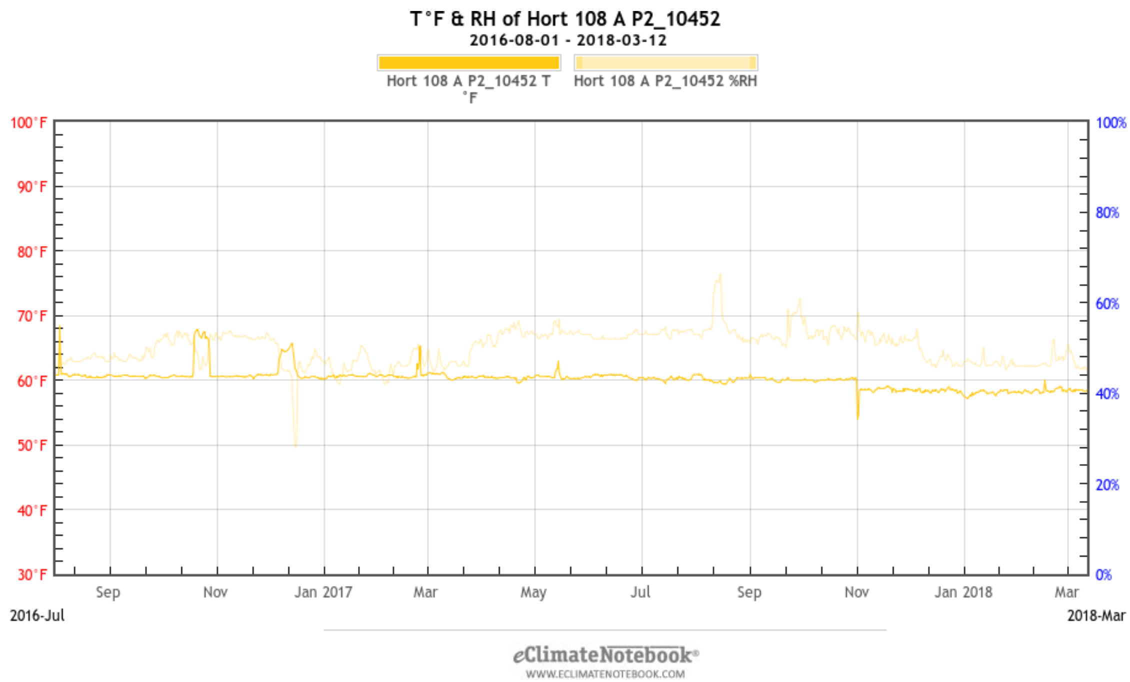


Figure 3: Temperature and RH of the 108 instrument storage room, July 2016-present

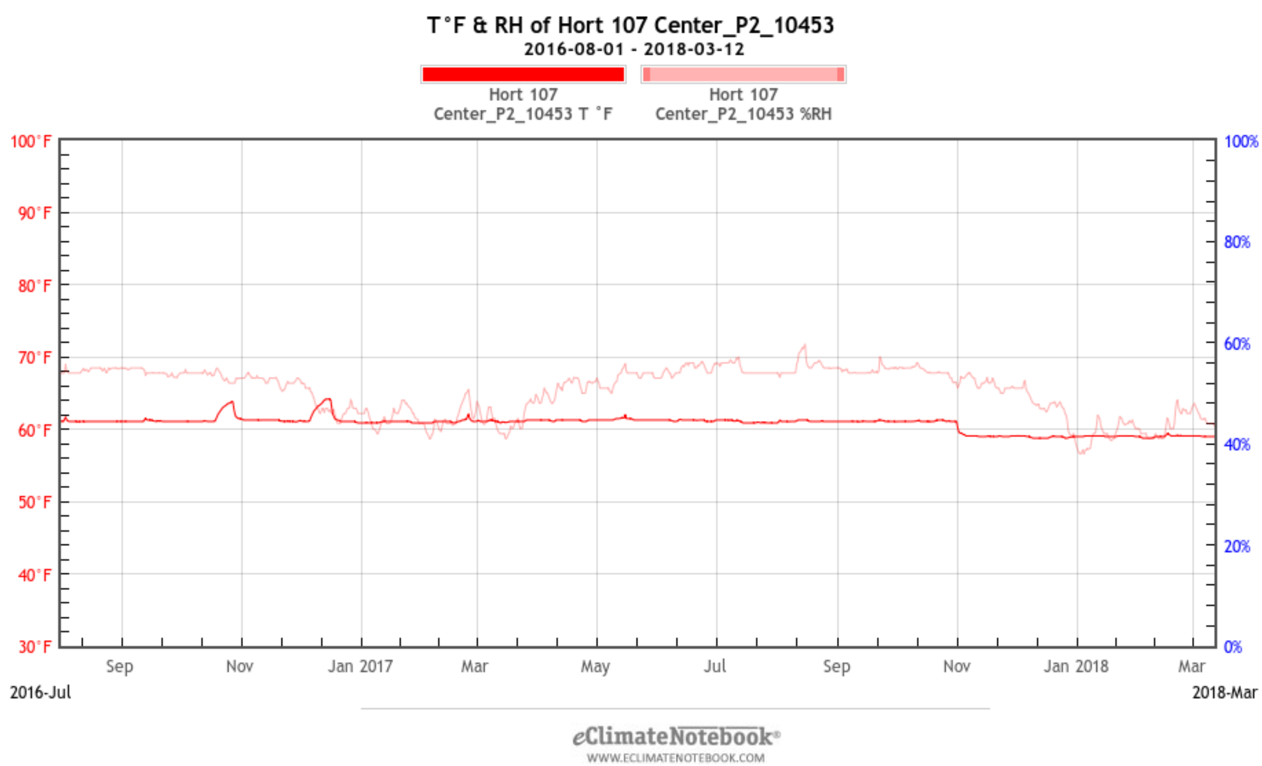


Figure 4: Temperature and RH for room 107 (floor 1 of the archives vault) July 2016-present

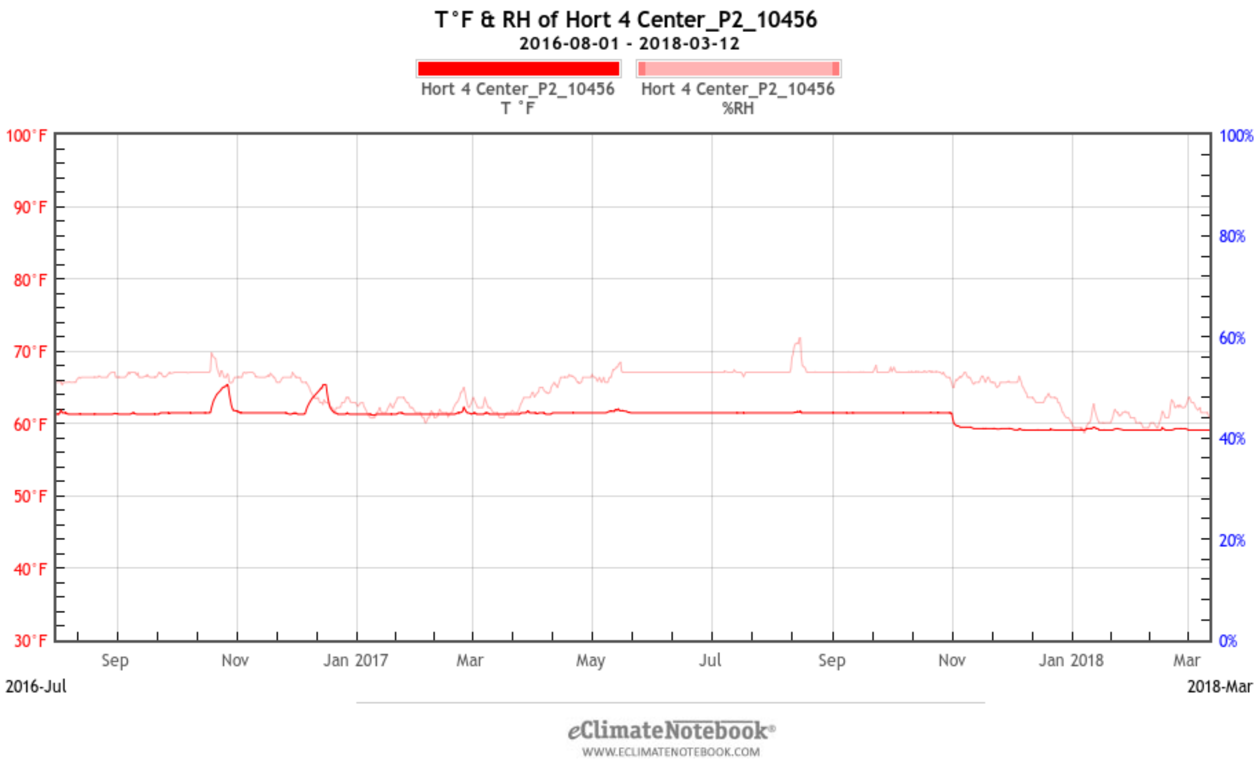


Figure 5: Temperature and RH for room 4 (basement level of the archives vault) July 2016-present

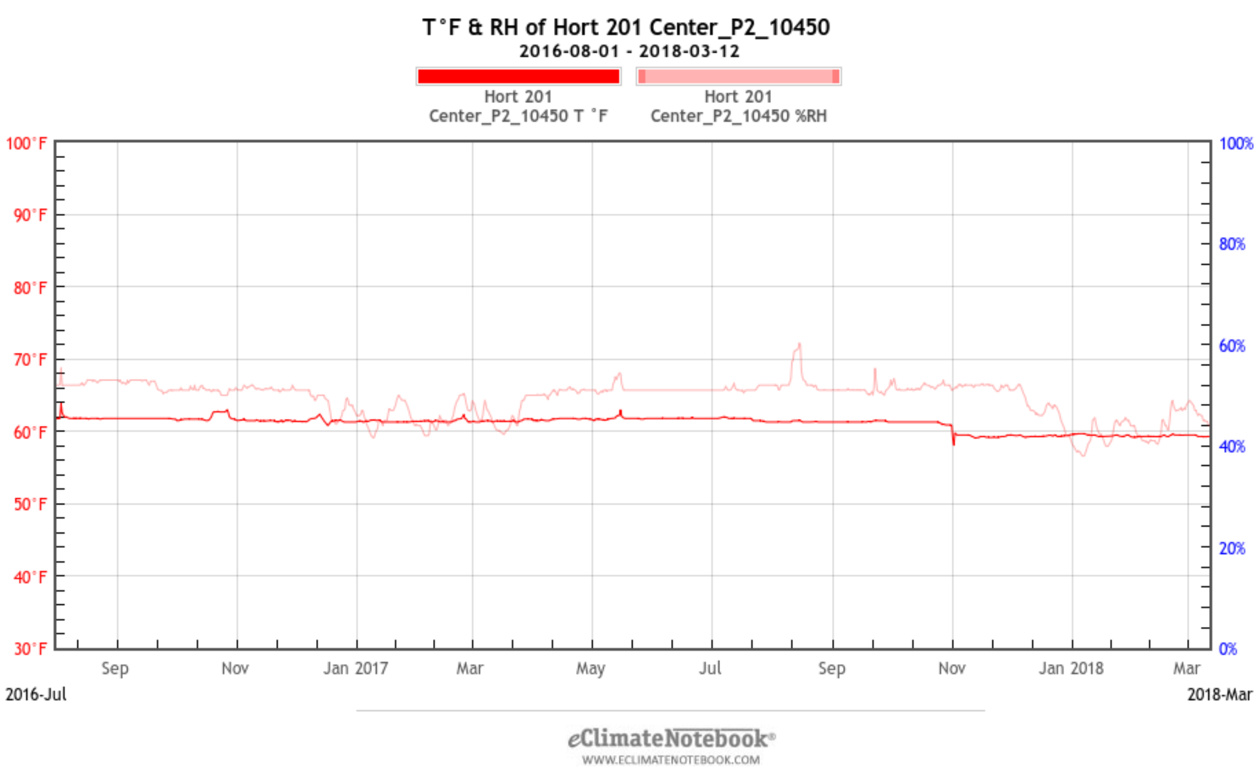
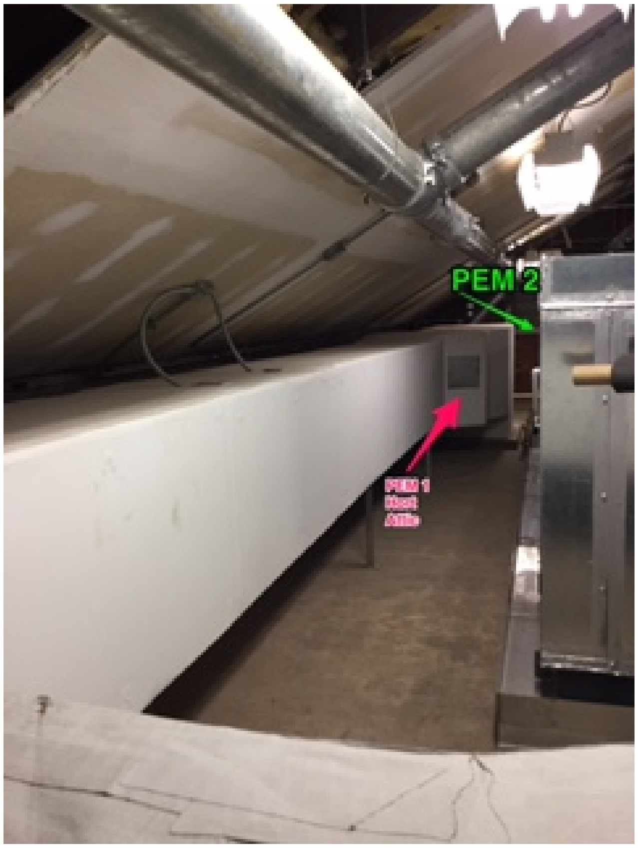


Figure 6: Temperature and RH for room 201 (floor two of the archives vault) July 2016-present

Appendix Two: Images

(clockwise from top left): *Image One:* The building in which the Archives Research Center resides, the Horticulture Field Lab ca. 1921. *Image Two:* Professor David Gottleib (plant pathology), ca 1950's performing research in the Hort Field Lab. *Image Three:* Decommissioned nitrogen refrigeration system before new HVAC system was installed in the vault in the early 1990s.



(clockwise from top left): *Image Four:* View of new AHU and ductwork in mechanical room with locations of PEM2 dataloggers. *Image Five:* Installation of exterior PEM2 datalogger to monitor outside environment immediate to the ARC building. *Image Six:* Kelly Krish installing a PEM2 datalogger into the new AHU.

(clockwise from top left): *Image Seven:* Longer view of the new AHU in the mechanical space with Leslie Lundquist (Library Facilities) and Bill Heinz (University Facilities and Services). *Image Eight:* the archival vaults, post HVAC remodel. *Image Nine:* Evidence of condensation on the outside of the AHU, prior to construction of an enclosure in the mechanical room.

Appendix Three: IPI Final Report

Mechanical System Design and Operation Recommendations

University of Illinois

Archives Research Center/Horticultural Field Laboratory

October 2013 – October 2017

Image Permanence Institute

Kelly Krish, Preventive Conservation Specialist

Christopher Cameron, Sustainable Preservation Specialist

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PROJECT OVERVIEW

In the fall of 2013, the University of Illinois contracted with the Image Permanence Institute (IPI) to make recommendations for the design and operation of the air handling unit that serves the collection spaces in the Archives Research Center in the Horticultural Field Library. These spaces house a significant amount of the archival materials held by the University of Illinois.

This evaluation was performed over a four-year period and included three onsite visits. IPI Preventive Conservation Specialist Kelly Krish and Sustainable Preservation Specialist Christopher Cameron conducted the final visit; former IPI Senior Preservation Environment Specialist Jeremy Linden was involved in the initial recommendations. All of the consultants worked with University of Illinois Libraries Professor and Head of Preservation Services Jennifer Hain Teper throughout the course of this project. The consultants also met with administrative and project staff at the end of each visit to inform them of findings.

Primary activities for visits included walkthroughs of collection spaces, review of data gathered from the University's environmental monitoring program, review of physical mechanical systems and the drawings and plans associated with them, and discussion of strategic goals and plans for preservation and collections management at the university in the foreseeable future. The goal of the project was to enable the University of Illinois staff to make informed, strategic decisions regarding long-term collection stewardship, space allocation, mechanical system operation, and sustainable preservation practices.

This report represents the final deliverable from IPI to the University of Illinois in fulfillment of the consulting agreement, and is organized as follows:

We greatly appreciate the opportunity to work with the staff and collections at the University of Illinois.

Kelly Krish, Preventive Conservation Specialist

Christopher Cameron, Sustainable Preservation Specialist

Image Permanence Institute

October 2017

Executive Summary

The current project focused on the design and operation of a mechanical system to serve the collection spaces- the Stacks (Rooms 4, 107, and 201) and the Instrument Vault (Room 108A)- at the Archives Research Center in the former Horticultural Field Laboratory. The spaces, formerly used for fruit and vegetable crop storage, have been retrofitted for the storage of archival materials and historic music instruments, but the former mechanical system was only able to provide conditions designed for human comfort, not long-term preservation.

The new mechanical system, AHU 1, is intended to provide lower temperatures with an appropriate range of relative humidity. This will slow the rate of chemical degradation of the materials, and mitigate the risk of mechanical damage. While the collection spaces are thus receiving improved environmental conditions, several observations were noted that could improve the preservation quality further and/or reduce the energy costs associated with achieving such conditions.

The main recommendation is to implement seasonal set points, with cooler temperatures and slightly lower relative humidity in the winter. This requires the mechanical system to do less work than it would to maintain summer conditions year-round while still keeping the collection safe. While it was intended from the project's outset that these set points be implemented, this was not done during the course of the project due to warranty limitations. As such, the system and spaces should be closely monitored through the upcoming winter to see how they respond to the seasonal set points.

It was found that most of the spaces responded to surrounding conditions more than originally thought. Thus, Room 201 required cooling in the summer and heating in the winter due to outside air conditions, whereas the other spaces needed cooling year-round. In the case of Rooms 4 and 107, this heat is believed to be coming from the surrounding hallways, which are maintained for human comfort. Room 108A though has a significant heat gain from the windows on the south side, which were not properly insulated during the retro-fit; insulating these should help the space to maintain cooler temperatures without as much mechanical work to do so.

Additional energy savings may be found through several measures. Overnight system shutdowns can be tested to see if the spaces can hold conditions; if possible, an 8 hour shutdown would reduce energy costs by roughly 33%. The speed of the dual fans can be adjusted to more closely match needs, and take advantage of the fact that reductions in fan speed relate to more dramatic reductions in horsepower. Finally, excess sub-cooling and reheating should be reduced in the winter to reflect that, unlike in summer when cooling is necessary for dehumidification, cooling here is only necessary to meet a temperature set point.

With the new system in place and continued experimentation with its operation, improved preservation and energy efficiency goals should be met.

LOCATION/ BUILDING

The University Library at the University of Illinois is made up of six facilities that together comprise the largest public university research library in the United States. One of these facilities, the Archives Research Center (ARC), holds over half of the University Archives' collections and is located in the former Horticultural Field Laboratory facility on the University's South Campus. The vault storage areas within the ARC are a three floor (11,314 sq. ft.) space constructed in 1921 for use in research on fruits and vegetable crop storage, and use of insecticides and fungicides.

As such, the room envelopes were originally designed to maintain consistent low temperatures. However, the mechanical system serving the spaces was designed for human comfort, with higher temperatures and greater fluctuation in relative humidity than is desirable for the long-term preservation of collections. An NEH Sustaining Cultural Heritage grant was received to replace the system with the new mechanical system described in this report, which now serves the collection spaces- the Stacks (Rooms 4, 107, and 201) and the Instrument Vault (Room 108A)- to deliver appropriate conditions.

COLLECTIONS

Established in 1963, the University Archives includes the collections of personal papers of students, alumni, and faculty, and the records of external professional and educational organizations including the American Library Association Archives. These receive a growing level of research use by internal and external researchers, and the general public. The materials include paper documents, photographs, and audiovisual materials (including video, film, and audio tape). These are housed in archival boxes on stationary metal shelving in the Stacks rooms.

There are also a number of historic instruments and associated materials (ex. uniforms) stored in Room 108A. These are composed of a variety of materials, including wood, leather, textiles, and metal. The instruments are stored in cases on stationary metal shelving; more shelving will be installed in this space as more instruments are added to the vault.

Preservation environment
In order to ensure the preservation of these materials, a quality environment needs to be provided, focused on avoiding high temperatures and controlling the relative humidity. Higher temperatures will accelerate the rate of chemical deterioration in the organics in the collection (particularly the book and archives), causing color change and embrittlement. Lower temperatures generally slow degradation rates, aiding in preservation. Inappropriate relative humidity (%RH) can cause damage to collections in the following ways:

- high %RH (here defined as above 55%RH) encourages mold germination, increased insect activity, metal corrosion, bleeding of colorants, and expansion of materials, as well as reinforcing the effects of other forms of deterioration
- low %RH (here defined as below 30%RH) can cause materials to become desiccated and physically shrink.

These high and low %RHs are approximate guidelines for general collections with a variety of materials. Fluctuations to new extremes can lead to cracking or separation of joints/layers, particularly if the material is restrained (as in music instruments).

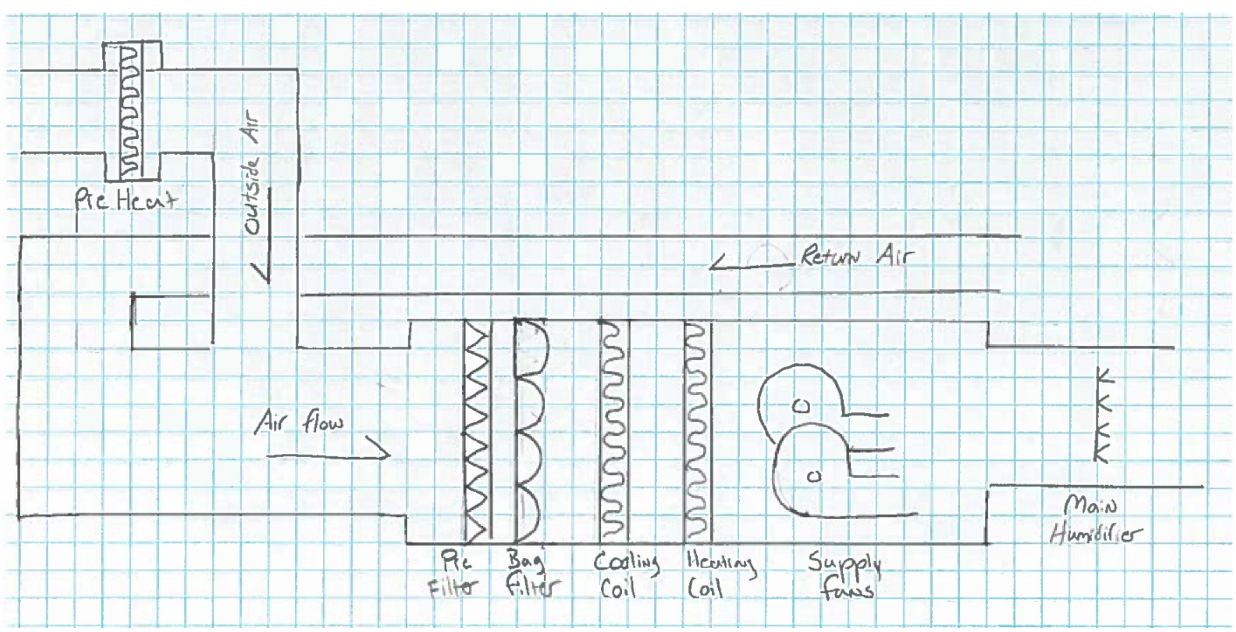
The effects of these environmental conditions can be taken into account using IPI's time-weighed preservation index (TWPI). This metric is based on experiments on the effects of temperatures and %RH on the rate of deterioration of organic materials. It takes into account the conditions experienced in a collection environment to provide a relative means of comparing preservation quality. The lower the TWPI, the faster materials will deteriorate.

Recommendations for preservation conditions depend on what can be achieved given the local climate, the building, the mechanical systems, the institution's goals, and the collection's needs. For this project, IPI worked with the University of Illinois staff throughout the planning process to establish appropriate environmental goals. AHU-1, described on the following pages, was installed to deliver these conditions to the collection storage spaces to support their long-term preservation.

AIR HANDLING UNIT 1 (AHU 1)

Location: Attic
Layout: Sub-cool/reheat system. The cooling coil is located inside the unit and the heating is performed by individual reheats downstream.
VFD: Yes- there are two supply fans, and each has a VFD
BMS: Yes
Zone Served: Stacks and Room 108A (Instrument Room)
Outside Air: None
Economizer: None
Heating: Downstream electric reheats
Number of VAV Boxes: 4
Humidifier: A humidifier is located on the main unit after the supply fan
A downstream humidifier is located with the 108A reheat
Cooling Coil: Chilled water with glycol
Design leaving dew point capability from the cooling coil: 43°F

Cartoon of AHU 1:



AHU 1 Logger Locations
Outside Air (Loading Dock), Return Air, Mixed Air, Cooled Air, Supply Air

AHU 1 SYSTEM OPERATION

Air Handling Unit 1 serves the Stacks (Rooms 201, 107, and 4) and the storage space for music instruments (Room 108A). The unit has a cooling coil, fans, and a humidifier. All heating is performed downstream by reheats. Booster humidification is available on the supply duct for Room 108A after the reheat.

As air is drawn into the ducts, it is mixed with return air from each of the spaces that are served by this unit. A supply duct for make-up/outside air is available; however, the duct has been manually closed. The return air blends with any outside air that has leaked past the dampers to become mixed air and is pulled through two sets of filters- a MERV 7 pre-filter and a MERV 14 final filter- to remove particulates and some gaseous pollutants.

The mixed air is pulled across the cooling coil. Here the air is cooled and, depending on the dew point of the passing air, may be dehumidified. After the cooling coil, the air will cross the heating coil. In others systems, this coil would reheat the passing air to the desired temperature downstream; in this system, the coil is off and does no work to the air because the downstream reheats allow the system to provide better control and more precise temperatures in the individual spaces.

After the heating coil, the air is pulled into the fan compartment of the unit. This system utilizes a two supply fan design. This two fan system uses less energy than a single large fan and provides greater energy savings through actions like reductions of fan speeds. The multiple fans also offer redundancy to the system and makes replacing parts easier. Air is pushed out by the fans and downstream into the supply duct. As the air enters the main supply duct, it will pass over the humidifier. Here, depending on the relative humidity of the passing air, moisture may be added to the air.

Leaving the humidifier, the air will now travel through the main duct until it branches off to one of four supply ducts. Each of these ducts serves a separate zone within the facility. Each of these zones has a reheat installed that will help further treat the passing air to the desired condition for that location. The zone that serves Room 108A has booster humidifier on it as well to help add moisture to the passing air. As the air passes through these zones, it is treated by the reheat- and, in the case of Room 108A, the humidifier- and exhausted into the collection space. Once the air is in the space, it will eventually be drawn back into the return for the system to begin the process over again.

Observations – AHU 1 Design and Operation

- This unit only serves collection spaces.
- The outside air for the system was closed off at the time of the final site visit.
- The main heating coil on the unit does not appear to be used. All heating is performed downstream by reheats.
- The unit had serious condensation issues when it was first installed. This issue has since been resolved.

Winter Operation

(Note that winter set points were not implemented during the grant period. If they were to be employed, operation would still be as described but resulting conditions would vary.)

As air is drawn into the ducts, it is mixed with return air from each of the spaces that are served by this unit. A data logger was placed in the return duct at the unit. The average condition of the air in this duct was 61°F/46%RH/40°F DP. The outside air remains closed; however, it does allow some air to leak by. This air has a minor effect on the return air. The blend of the two air streams creates an average mixed air condition of 60°F/50%RH/41°F DP. The mixed air is then pulled through two sets of filters (pre-filter, final filter).

The mixed air is pulled across the cooling coil, where the air is cooled and, depending on the dew point of the passing air, may be dehumidified. The average winter condition for the air passing the cooling coil is reduced to around 48°F/72%RH/41°F DP. After the cooling coil, the air will cross the heating coil, which, in this system, is normally off and does no work to the air.

After the heating coil, the air is pulled into the fans of the unit and pushed downstream into the supply duct. The air exiting the unit before the humidifier showed an average condition of 49°F/73%RH/41°F DP. As the air enters the main supply duct, it will pass over the humidifier and its effects can be measured at the supply air loggers.

Leaving the humidifier, the air will travel through the main duct until it branches off to one of four supply ducts, which each serve a separate zone within the facility. The air is reheated at each supply by 8-13°F and air entering Room 108A also passes by a booster humidifier. Data loggers on the supply air for each of the spaces show the following average conditions (again, note that the system was still operating to provide summer conditions during this time):

Room 4 (Basement): 60°F/48%RH/40°F DP

Room 107 (1st Floor): 60°F/48%RH/40°F DP

Room 108A (1st Floor): 57°F/55%RH/41°F DP

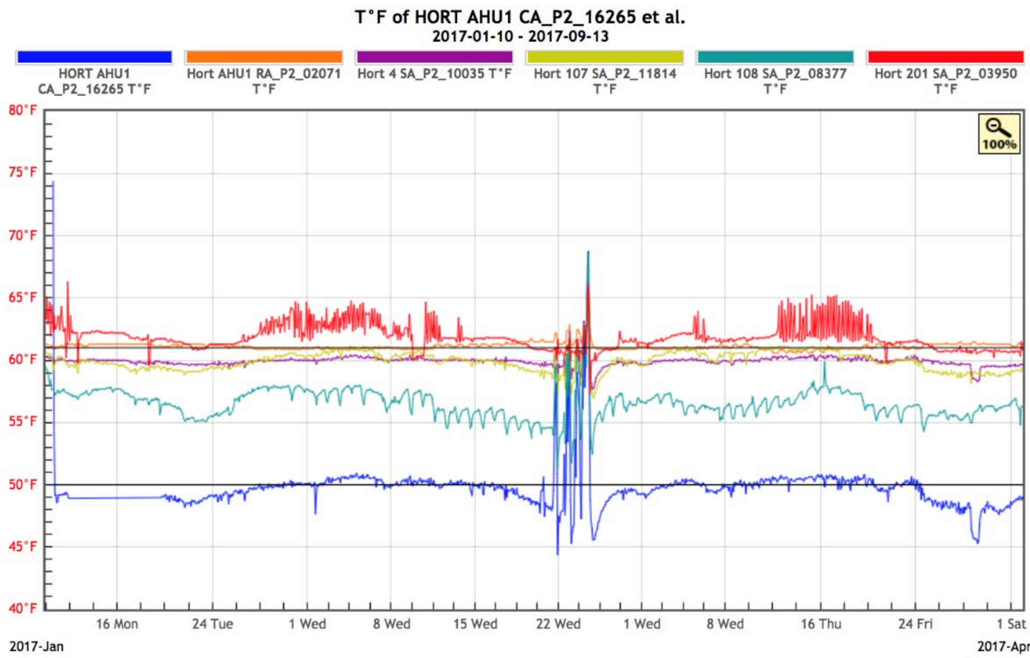
Room 201 (2nd Floor): 62°F/45%RH/41°F DP

The dew point for all of the spaces remains close to the supply air dew point. This indicates that the main humidifier and the Room 108A humidifier add very little moisture to the passing air.

Evaluation of Operation

The data does not include the erratic increases in temperature from February 21st - 25th that may be attributed to a malfunction in the unit. These manifest only slightly in the downstream supply conditions.

The unit appears to be cooling all winter long. Return air is brought back into the unit around 61°F and is then cooled to 50°F at the cooling coil. The air is then sent to the reheats and heated back up at least 55°F to be discharged into Room 108A, the coolest room. In this situation, the system does a total of 16°F worth of sensible heating and cooling to the air. The other zones will use more energy, due to the fact that they have higher temperatures. During the winter months, there is no need to operate the cooling coil this low. A discharge air temperature off the cooling coil of 54°F would significantly reduce the work performed at the cooling coil as well as by the reheats. (The numbers may vary when winter set points are implemented, but excess sub-cool/reheat operation should still be avoided.)



Return air (orange) is cooled at the cooling coil (blue) and then reheated to the supply conditions at each room (purple, yellow, red, and teal).

Observations – AHU 1 Winter Operation

- There is very little outside air used and what is used can be attributed to leakage.
- The heating coil at the unit is not used.
- The cooling coil operates year-round.
  - The temperature of the cooling coil in the winter may be lower than necessary.
- The humidifiers do not add much to the passing air.

Summer Operation

As air is drawn into the ducts, it is mixed with return air from each of the spaces that are served by this unit. A data logger was placed in the return duct at the unit. The average condition of the air in this duct was 61°F/55%RH/45°F DP. The outside air remains closed; however, it does allow some air to leak by. This air has a minor effect on the return air. The blend of the two air streams creates an average mixed air condition of 62°F/56%RH/46°F DP. The mixed air is then pulled across two sets of filters (pre-filter, final filter).

The mixed air is pulled across the cooling coil, where the air is cooled and, depending on the dew point of the passing air, may be dehumidified. The average summer condition for the air passing the cooling coil is reduced to around 47°F/97%RH/45°F DP. After the cooling coil, the air will cross the heating coil, which, in this system, is normally off and does no work to the air.

After the heating coil, the air is pulled into the fans of the unit and pushed downstream into the supply duct. The air exiting the unit before the humidifier showed an average condition of 46°F/93%RH/43°F DP. As the air enters the main supply duct, it will pass over the humidifier. At this time of year, the humidifier should be off and add nothing to the passing air.

Leaving the humidifier, the air will travel through the main duct until it branches off to one of our supply ducts, which each serve a separate zone within the facility. The air is reheated at each supply by 10-14°F and air entering Room 108A also passes by a booster humidifier. Data loggers on the supply air for each of the spaces show the following average conditions:

Room 4 (Basement): 60°F/56%RH/44°F DP

Room 107 (1st Floor): 60°F/58%RH/45°F DP

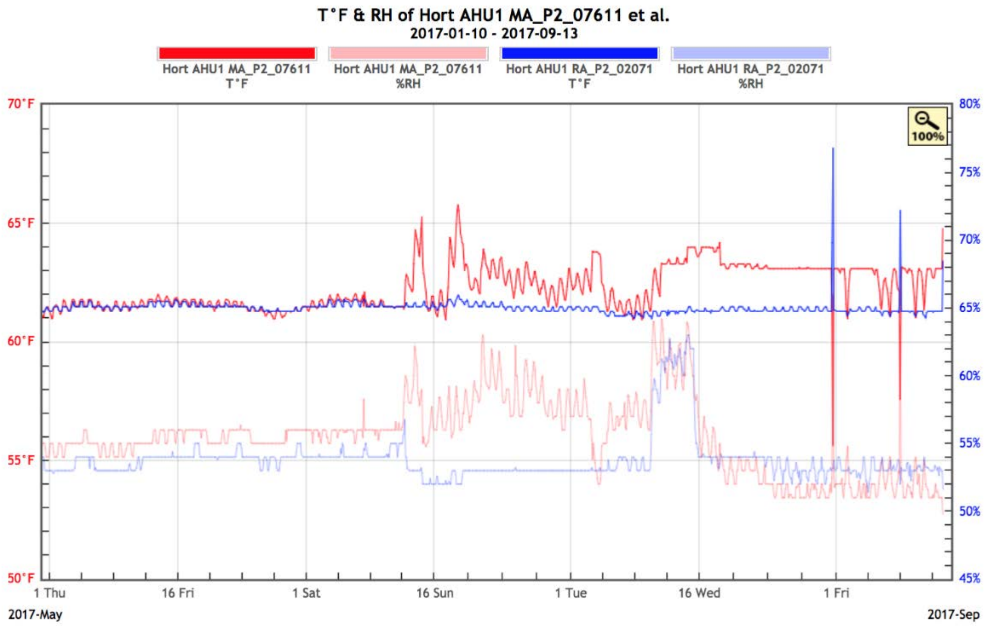
Room 108A (1st Floor): 56°F/64%RH/44°F DP

Room 201 (2nd Floor): 60°F/56%RH/44°F DP

Evaluation of Operation

The data does not include the erratic swings from August 10th - 15th that may be attributed to a malfunction in the unit.

THE AMOUNT OF OUTSIDE AIR USED BY THE SYSTEM CHANGES AFTER JULY 12TH. THE TEMPERATURE AND RELATIVE HUMIDITY INCREASES FROM THE RETURN AIR TO THE MIXED AIR, INDICATING THAT THERE IS OUTSIDE AIR BEING BROUGHT INTO THE SYSTEM. THIS AMOUNT OF AIR IS SMALL, BUT INDICATES A CHANGE IN THE OPERATION OF THE OUTSIDE AIR DAMPER.



Observations – AHU 1 Summer Operation

- The cooling coil is achieving a 45°F dew point.
- The heating coil at the unit remains unused.
- The amount of outside air used was minimal until July 12th. Since that time the system appears to be using some outside air.

Collection Spaces

Dataloggers were installed in the following locations to monitor the conditions provided by AHU 1:

- supply and return air for Rooms 4, 107, 108A, and 201
- north, center, and south spaces for Rooms 4, 107, and 201
- center space for Room 108A

Environmental Assessment

The collections spaces served by AHU 1 experience environmental conditions equivalent to TWPIs 60-71. This is a preservation quality better than those controlled only for human comfort (TWPI 39), but could be improved to support the long-term preservation of the collections, primarily by instituting the winter set points this coming season.

Target conditions

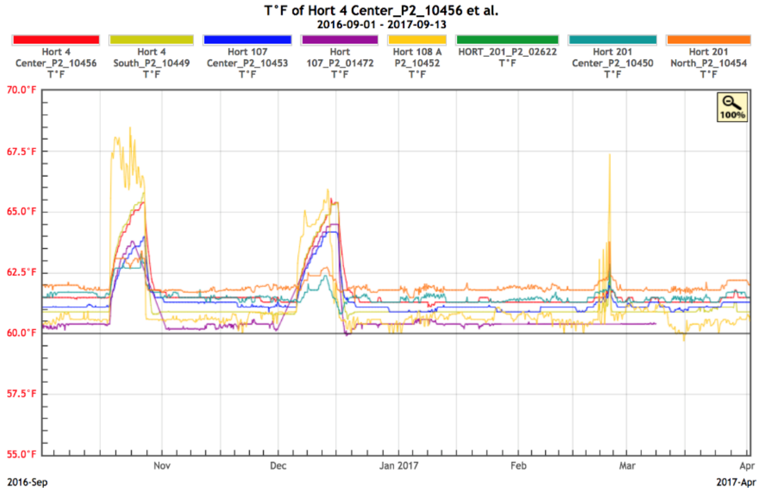
Storage Space within ARC	Summer Temp (°F) & RH	Allowable Fluctuation	Winter Temp (F) & RH	Allowable Fluctuation
Vault	60 (°F) 55%	+/- 5	50 (°F) 30%	+/- 5
Instrument Storage	60 (°F) 55%	+/- 5	50 (°F) 45%	+/- 5

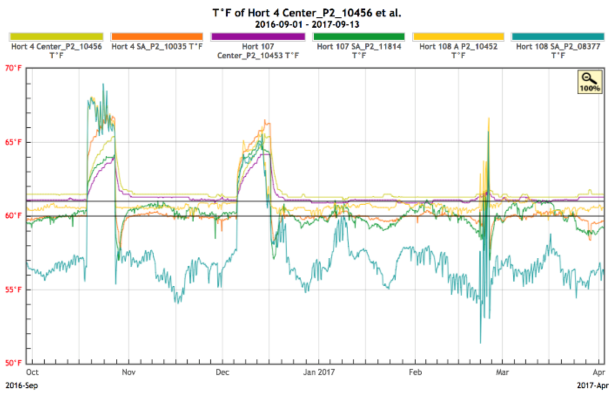
(Graphic by Jennifer Hain Teper)

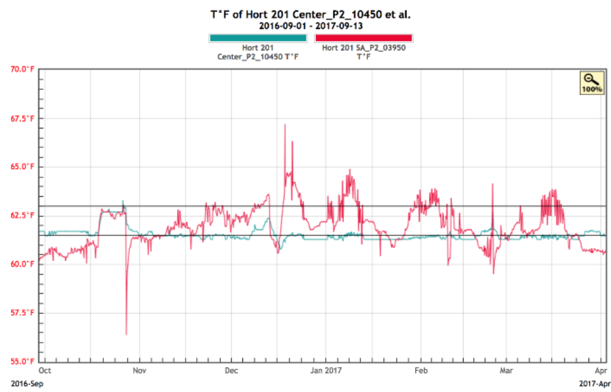
These conditions allowed for temperatures that were lower than with the previous system in both summer and winter, thus slowing the rate of chemical deterioration as well as reducing the amount of work the system should have to do to meet set points. It also had more control over relative humidity, particularly for Instrument Storage, which will help to prevent mechanical damage.

Winter conditions

Thus far, winter set points have not been implemented, so the system continued to target 60°F throughout last year. This resulted in temperatures between 60-62°F in the spaces with periods in October and December that reached 65°F and, in the case of 108A, 68°F. These periods are believed to be the result of mechanical issues that have since been addressed. However, preservation could be greatly improved by implementing the lower winter set points to bring the average temperature down as well.





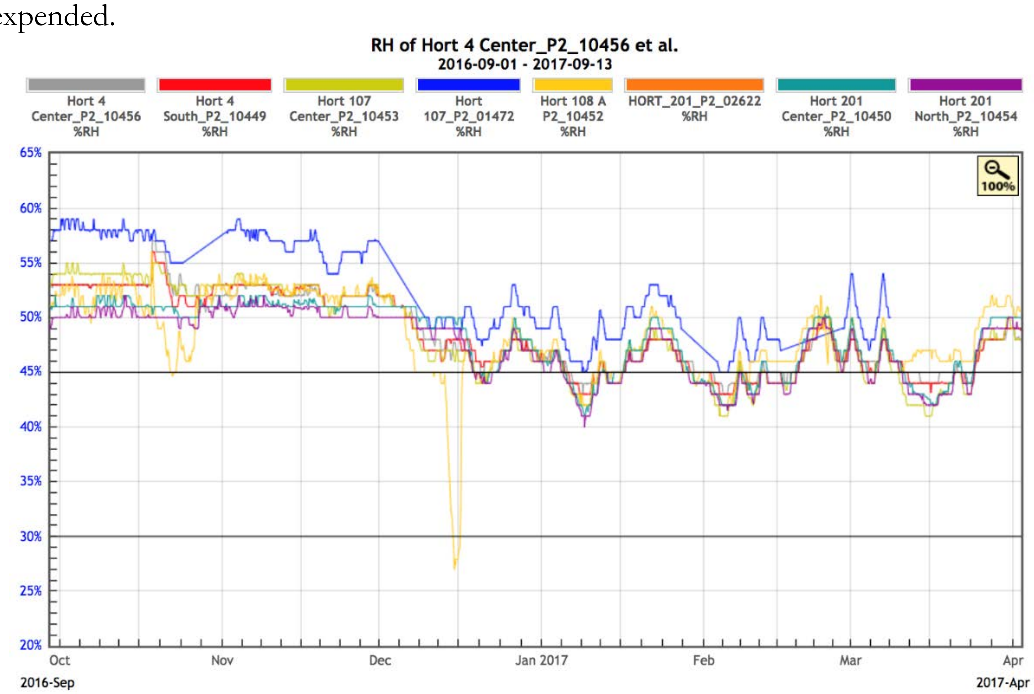


It is interesting to note that for Rooms 4, 107, and 108A, the supply air remains cooler than the spaces even in the winter, likely meaning that the spaces are receiving heat from the hallways around them that the mechanical system then has to work to counter. This has implications for the operation, as it may be that passive operation to allow the space to naturally drift down to lower temperatures in the winter is not as much of an option as originally thought.

Room 108A in particular is heating up significantly, though not from surrounding spaces but possibly as a result of the windows. These were not properly insulated when the space was retrofitted, and the temperature difference at the windows is noticeable from the interior of the building with an infrared camera. Improving the insulation around the windows, especially on the south side of the room, may allow the room to more easily meet lower temperature set points.

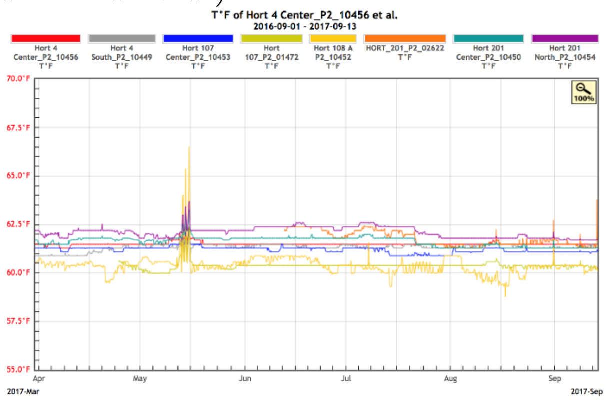
Room 201 is the only room in the Stacks that is receiving warmer supply air than the space temperature, indicating that it is affected by cool winter air. This could be partially a result of air infiltrating through the building envelope and the lower temperature of the less-occupied hallway on this floor. Thus, this room is the one that responds closest to what was predicted, where it may be possible to allow it to naturally drift down to the winter set point.

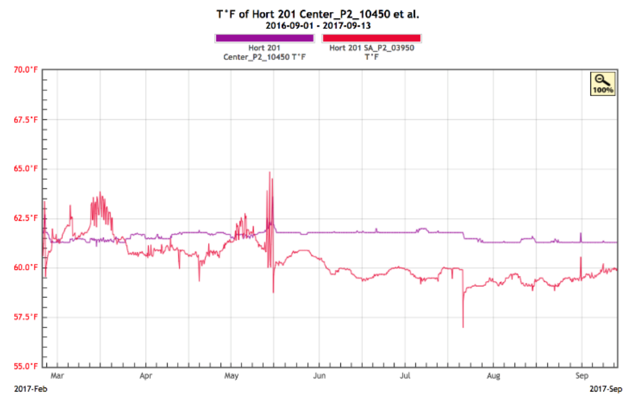
As a result of the summer set points remaining in place throughout the winter, the relative humidity in all of the spaces was higher than recommended for the winter. This means the humidifier was working harder and, therefore less efficiently, than was necessary for preservation. If winter set points are employed this year, the humidifier will be able to meet the lower set points with less energy expended.



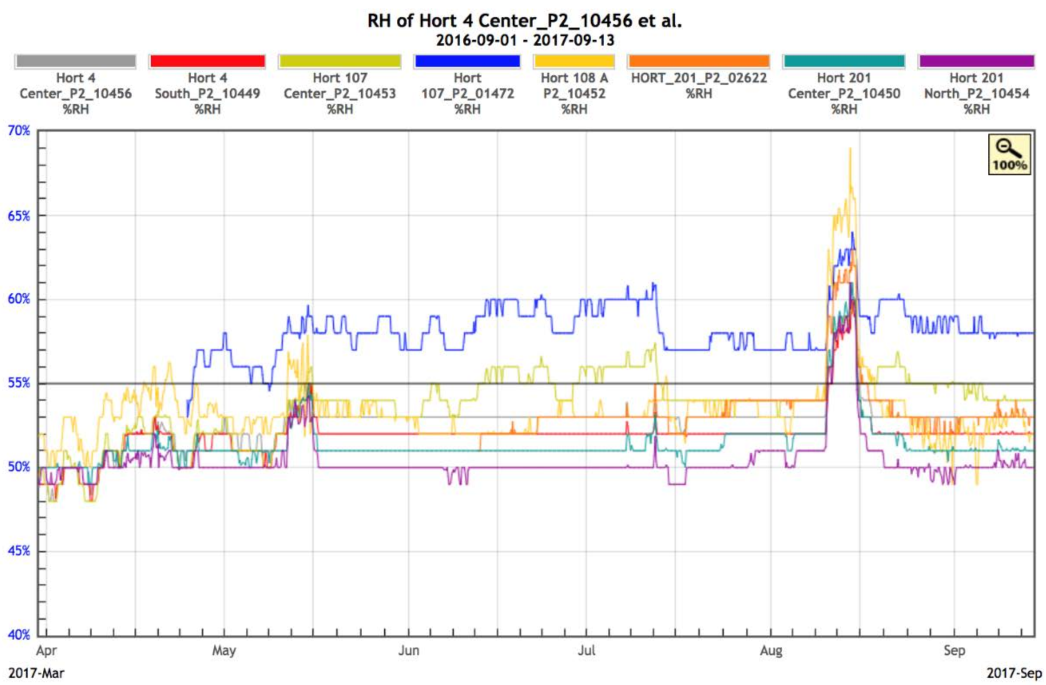
Summer conditions

During the summer months with a target of 60°F, the spaces typically ran 60-62°F. Room 201 was the warmest since, like in winter, it seems to be affected by outside air conditions more, possibly as a result of air infiltrating through the building envelope. This manifests itself in the supply air condition, which switches in April from heating the space to cooling the space. All of the other spaces must be actively cooled year-round, since they are affected by the surrounding hallway spaces (in the case of Rooms 4 and 107) and other building envelope issues (in the case of Room 108A with the windows).





With an exception during the month of August during what is believed to be a mechanical failure, all of the spaces stayed within the target range of 55%RH +/- 5%. It is interesting to note though that Room 107 seemed to have a higher relative humidity than the other rooms; in fact, Room 107 is higher than the other rooms year-round. This may be due to a slightly lower temperature artificially raising the relative humidity or a source of moisture in the room. Slightly raising the temperature (by 1°F or less) for the reheat for this room may help to prevent the relative humidity from exceeding 60%RH during the summer months, mitigating the risk of mold germination and increased insect activity.



GOALS AND SUGGESTIONS FOR AHU 1

1) Reduce excess sub-cooling in the winter season.

There is potential for the air handling unit to reduce the amount of cooling used during the winter months to help provide energy savings. Currently, the air handling unit cools all year round, cooling to the same conditions in the winter months as the summer months. However, in the winter months, the system is in heating mode and does not need to dehumidify. Therefore, less cooling can be used since the air on each unit only needs to be cooled to the lowest supply air temperature for the zones it serves. This could have a significant impact on the amount of sensible work performed by the units.

This operation drastically reduces the use of the cooling coil in winter months, saving energy from its operation and reducing the amount of reheat energy that is required by creating a higher baseline temperature from which to heat. A review of the winter discharge zone temperatures should verify the reheat temperatures and which unit is the coolest. The systems can be adjusted based off of this data.

It may also be possible to use more outside air in the winter rather than only the cooling coil to provide cooler temperatures. This will result in more humidification, but, if the humidifier can adequately meet the demand, the energy costs associated with this approach are lower. When implementing this strategy, it should also be checked that the outside air is not preheated too high (above 50°F for the winter set point) so that the system operation removes the benefit of using outside air.

2) Check the status of the relief air and outside air.

According to the data available, the system appears to be using some outside air though the damper is closed. The amount of outside air being used should be checked to verify that the damper control is closed and not allowing excess air in. With low occupancy, there is less need for fresh air so limiting the amount of outside air used can save energy. While the use of outside air is necessary at times, bringing outside air into an HVAC system involves energy use, particularly in the summer, the high outdoor dew point requires that any outside air brought into the system be dehumidified, using the cooling coil to sub-cool the air, which then needs to be reheated.

Reducing the use of outside air will mitigate potential moisture issues. However, state and local codes and regulations should be checked to ensure that there is not a required minimum outside air requirement that is mandated.

3) Identify the cause of the heat load in Room 108A.

During the last on-site visit, a year-round cooling load was identified in Room 108A. The load averages around 4°F in the summer and 3°F in the winter. The space has three exterior walls, all of which have windows that have been covered up. An examination of the space revealed that the walls appeared to be insulated with expanding foam. The roof of the space did also appear to have to two layers of fiberglass insulation as well. The walls and ceiling should allow the space to resist exterior loads that may be placed on the envelope. This means that the space temperature should very closely resemble the supply air and return air temperatures.

Unfortunately, the space load indicates that there is some outside influence on the room. The influence can potentially be from the mechanical room below, thermal bridging through the studs, or a thermal load on the exterior side of the covered windows. Measurements made at the time of the visit showed that the seam around the window panels was almost 30°F warmer than the space. These measurements were taken during a cool and cloudy day, and the load would be expected to be even greater on a warm sunny day. The University should investigate the space to determine what is influencing the cooling load on the space. Identifying and resolving the issue will better allow the space to hold a temperature which will affect the energy efficiency.

4) Install doors sweeps.
The University should consider installing a door sweep on the entry door to Room 108A. The door on Room 108A provide insects an open channel to move into or out of the space. The gap at the bottom of the door can be the most common path for the insects to use. This path can be obstructed through the use of door sweeps. These sweeps are broom-like accessories that attach to the base of the door. These sweeps prevent insects from entering under the door and help push dirt and debris away from the door when it opens. The sweeps can also potentially block or slowdown air from entering or leaving a space.

5) Continue to monitor and investigate the source of the insect issues in the Stacks.
Staff have identified through their Integrated Pest Management (IPM) program an issue with beetles and book lice on all three floors of the Stacks this past winter. These are interior spaces with no food present so their presence is unexpected. They therefore may indicate a moisture issue in the room walls that may not be detected by the dataloggers, which are more centered in the room. Walking around the exterior of the Stacks, there were signs of water damage, but the date of the damage was unknown.

There was a concern that if the vapor barrier in the walls was not adequate, running the Stacks at lower temperatures than the surrounding spaces could be allowing moisture to condense in the walls, thereby attracting insects. However, staff confirmed that the vapor barriers in the Stacks were checked and found to be appropriate for the conditions. Therefore, the cause of the insect issue is unknown but continued monitoring through this coming winter may help to illuminate the cause and potential mitigation measures.

Energy Savings Tests

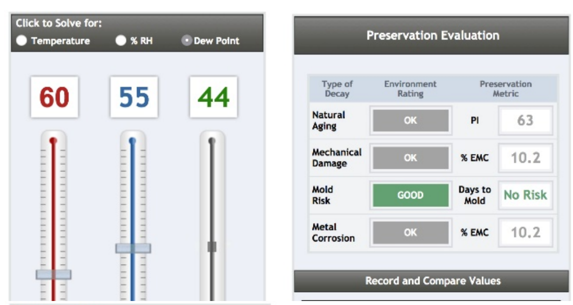
1) Shutdowns
The University should consider instituting the use of nightly shutdowns of the AHU in the facility. The University should test the shutdowns to ensure that the new equipment can perform these operations, the spaces can hold their temperature, and that the staff are comfortable with the results. The test should range from 4 to 6 hours overnight each day for two weeks. During this time, the system is completely shut down and the outside air remains closed. This will test the ability of the spaces served by the AHU to hold the temperature against any heating or cooling loads within the space.

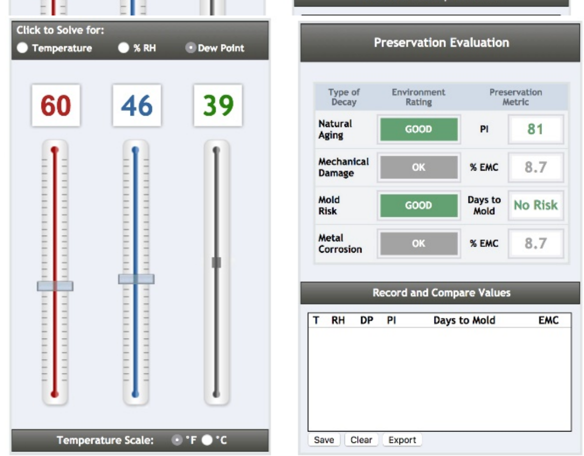
The shutdown tests should be performed twice, once in the summer (July/September) and once in the winter (December/March). Because some staff work in the collection spaces, the tests should be performed in the evening so there is no issue with human comfort or air quality. Optimal hours for overnight shutdowns start between 10PM and midnight, with the system coming back online around 6AM. This would allow facilities staff to address any issues that may occur during the shutdown.

During the shutdown test, the area should be monitored by data loggers and data should be pulled daily from loggers and analyzed to ensure there are no issues in the space so that conditions remain in a safe range for the collection materials. Data should also be monitored to ensure that the space temperature fluctuations during the shutdown are not greater than 2-3°F during the course of the shutdown. If at any point the conditions exceed the safe range or the temperature fluctuations are too great, the test should be halted and the data should be examined. If the spaces show no change in condition, longer shutdown tests can be considered. Instituting an 8-hour a day shutdown would reduce energy consumption by the unit by roughly 33%.

2) Use seasonal set points

Many institutions utilize set point changes as a way to passively use seasonally cool and dry outdoor conditions to help reduce temperatures and raise RH inside a facility. Seasonal set points are generally used during both the winter and summer months to improve the quality of the preservation environment and conserve energy. Lower temperature set points are usually instituted in the middle or end of the fall season and then raised to summer temperature set points in early to mid-spring. Lowering the temperature during the cool season will increase the normally seasonal low relative humidity and result in a better preservation environment.

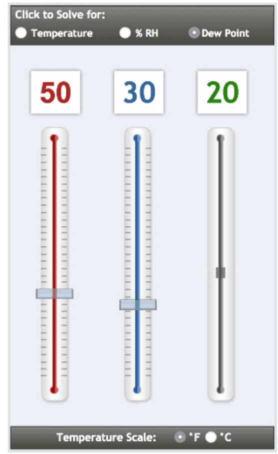


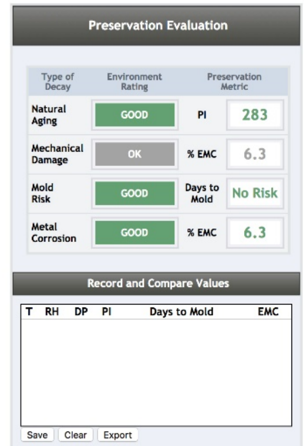


Over the summer (late May – Sept) of 2017, the system produced an average space condition, for all spaces, of 60°F/55%RH/44° DP based on a comparison of data available from the space loggers. This produced a preservation index rating of 63. By comparison the preservation index for a space operating at standard room conditions of 70°F/50%RH/50° DP is 39. The unit appears to be operating to the best of its abilities during the summer months. Any reduction in temperature of the spaces in summer may lead to increase in RH. The increases could potentially cause the RH levels to reach the point of mold germination. The university should continue to operate the system to these conditions in the summer months for all of the supplied spaces.

The winter seasons (November - March) provide better opportunities for both preservation improvement and energy savings. The current average winter conditions for the paper vault spaces was 60°F/46%RH/39° DP. This produces a preservation index of 81. This temperature condition is based on an average condition of from the three space loggers in the vaults. Though the winter preservation index is good, the potential exists to make it better.

The desired set points for winter operation would create one cool common condition for all floors of the Stacks. The set points would use cooler temperatures to improve the preservation quality of the collection environment and reduce the amount of humidification. The desired set points for the winter season should be 50°F/30%RH/20° DP. The cooler temperatures within the collection space will increase the longevity for all of the items stored here, improving the preservation index rating to 283. The relative humidity will be within the elasticity range for the materials and should reduce the likelihood of damage from dryness.





Due to limitations of the collections, the instrument vault cannot use the same conditions. The current average winter conditions for the instrument vault spaces was 60°F/55%RH/44° DP. This produces a preservation index of 63. The desired set points for the winter season, for the instrument vault only, should be 50°F/45%RH/29° DP. The cooler temperatures within the collection space will increase the longevity for all of the items stored here, improving the preservation index rating to 182.

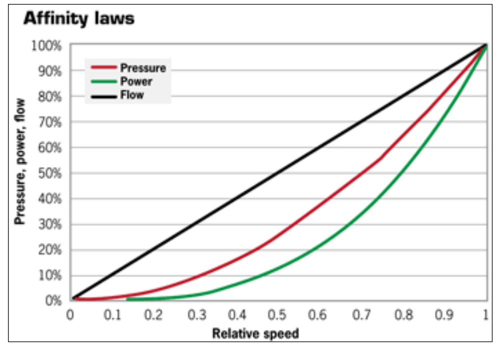
The intention is not to use outside air to produce a cooler temperature but less heating of the supply air to produce a cooler temperature. In this scenario, the return air is brought back into the system slightly cooler than the supply air due to a heating load on the space. This air combines with minimal outside air to become mixed air. The condition of this mixed air may now be slightly cooler than the return air. When this mixed air reaches the heating coil, the air is heated to a desired temperature for the space. The lower the desired space temperature, the less work the heating coil needs to perform to achieve it.

If 1 & 2 are not possible, an alternative test is described below.

3) Fan Speed Adjustments

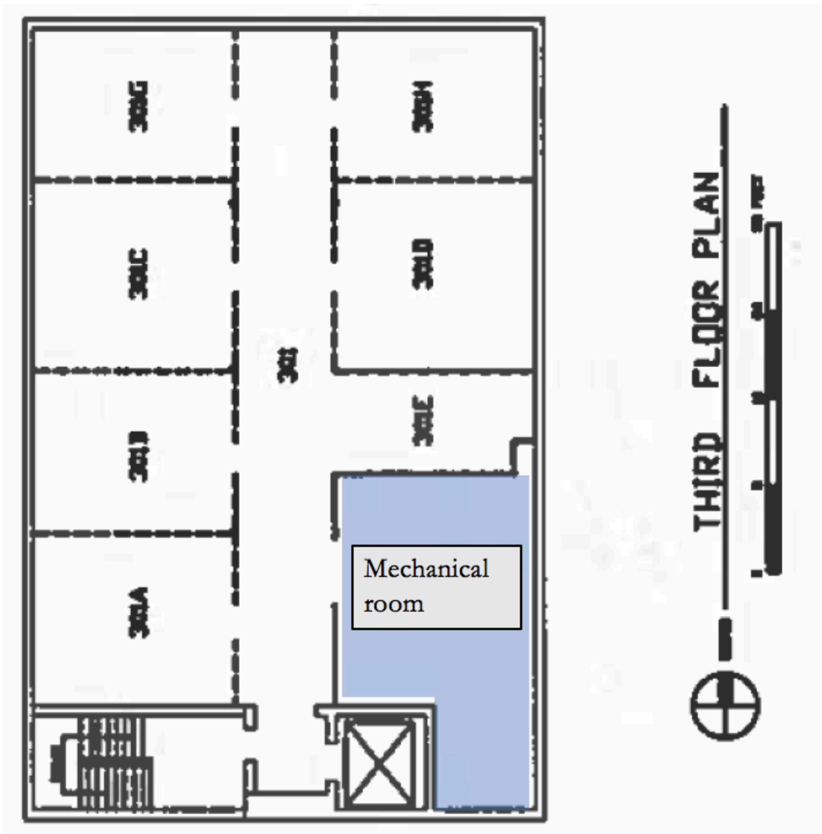
Both of the fans have a variable frequency drive (VFD) that control them. It may be possible to achieve substantial energy savings through managed control of the VFDs and fans. The fan motors on air handling units' account for most of the electrical consumption by the units. AHUs operate better with the installation of a VFD. These drives are meant to vary the frequency and voltage that is supplied to the fan motors. The VFD can allow the speed of the fans to be matched with the load requirements. When the facility does not need to operate at peak load conditions, the fans can slow down and use less energy.

The fan power consumption does directly relate to the fan speed and the flow of the air. Any given reduction in fan speed results in a cubic reduction in fan horsepower. Slowing the fan speed down to 50% may mean a 50% reduction in the flow of air but will also yield an 87% reduction in horsepower. Strategies like this can be effective to save energy after hours when a facility is unoccupied and less air flow is needed. By using a VFD, you can control the fan to adapt the air flow to the needs of the system. Reducing the overnight fan speeds can lead to long term energy savings from the unit.

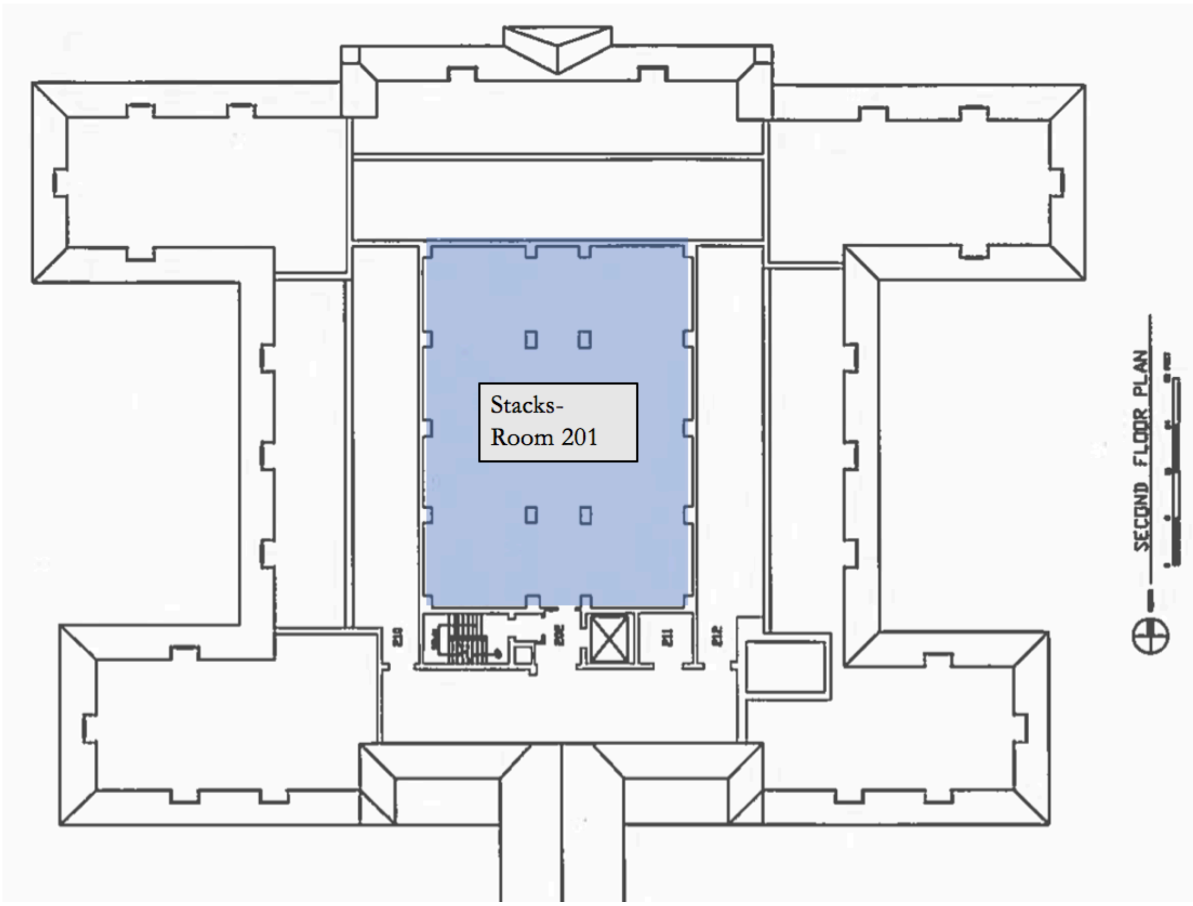


Appendix 1 – Floor Plan

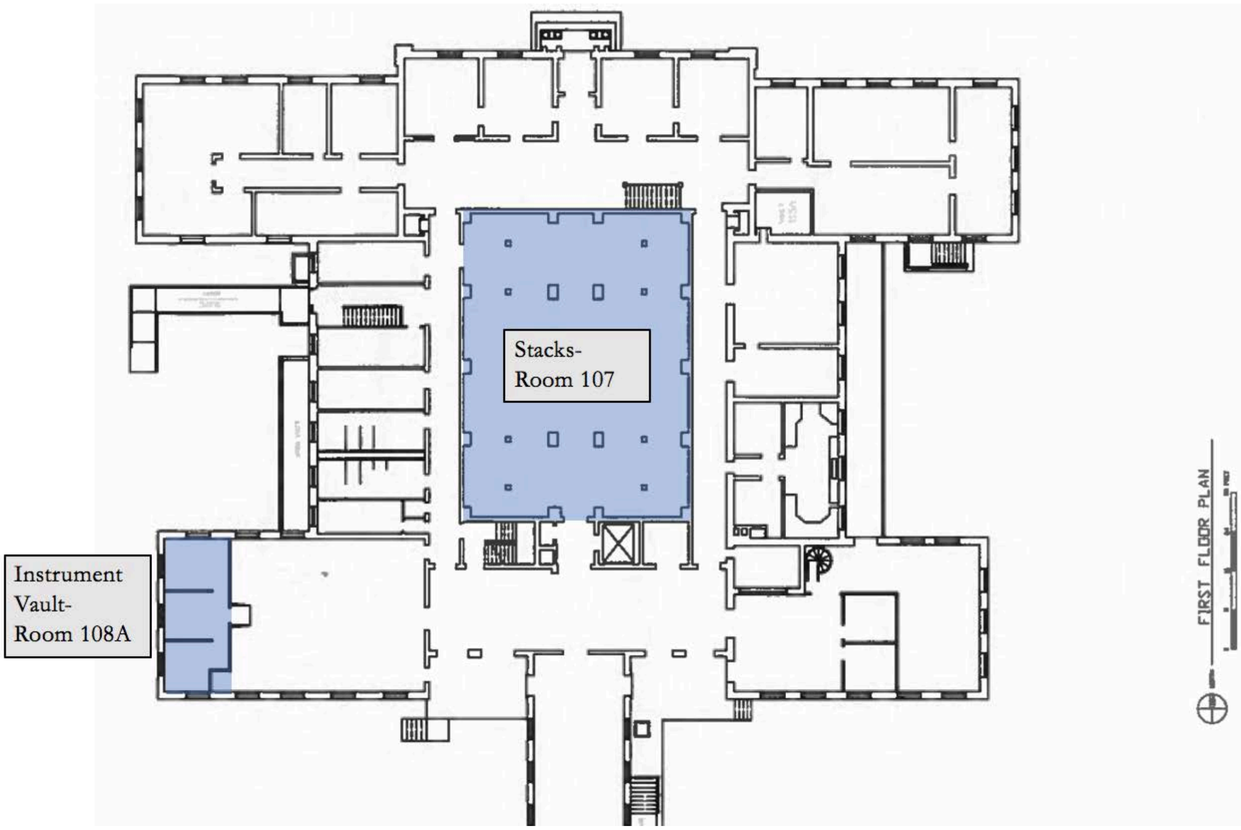
Third Floor



Second Floor

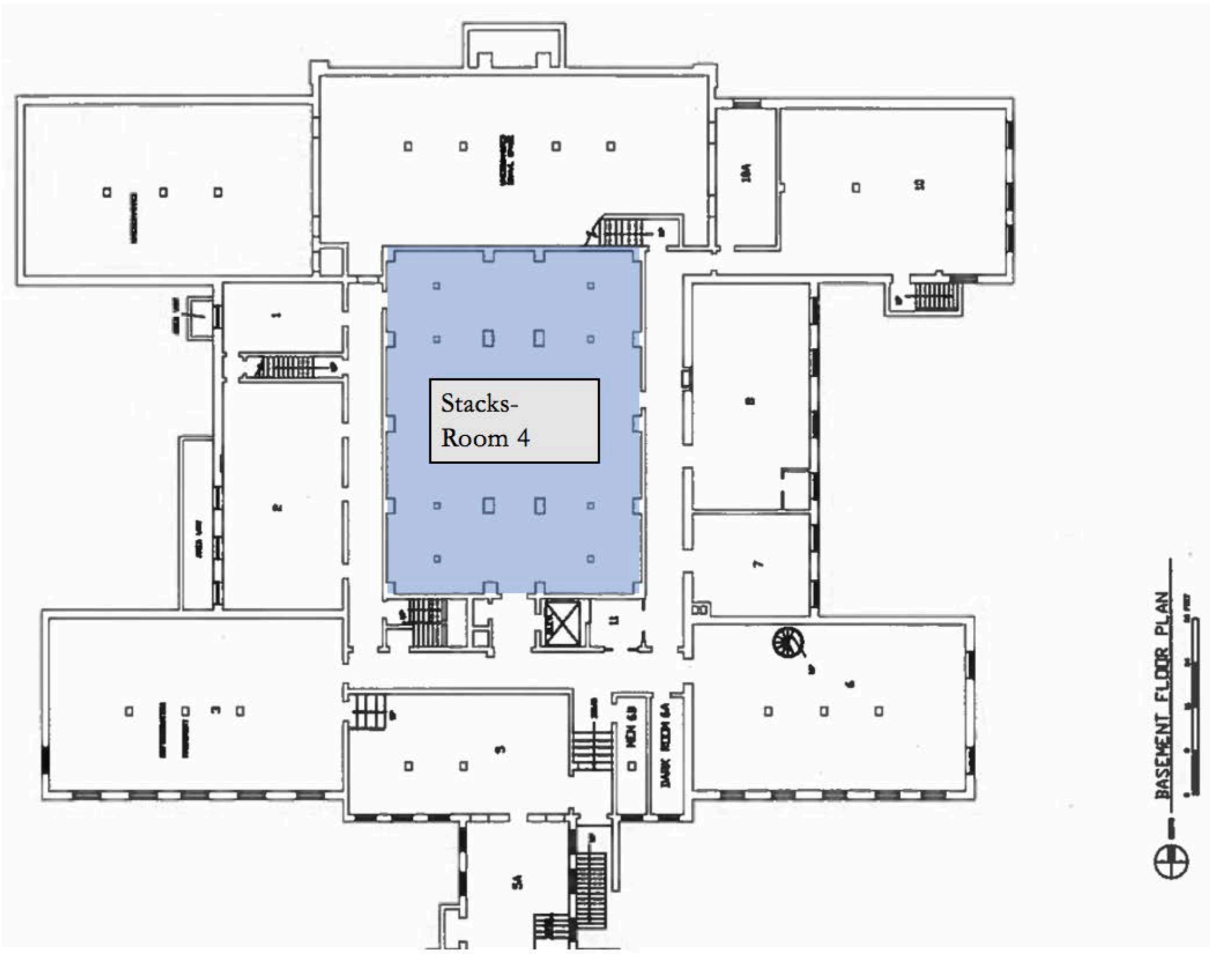


First Floor



Stacks-
Room 107
Instrument
Vault-
Room 108A
FIRST FLOOR PLAN

BASEMENT FLOOR



APPENDIX 2 – IPI'S PRESERVATION METRICS

Natural Aging

Measures:

The rate of "natural aging" as determined by the rate of spontaneous chemical change in organic materials.

- TWPI integrates the T and RH values as they change over time into a single estimate of the cumulative effects of the envrionment on the rate of chemical decay.
- TWPI is helpful as a quantitative comparison of the preservation quality of different storage locations or environments.

Applies to:

All Organic Materials (paper, textiles, plastics, dyes, leather, fur, etc).

TWPI Metric	Interpretation
TWPI > 75	GOOD
45 < TWPI ≤ 75	OK
TWPI ≤ 45	RISK

Metal Corrosion

Measures:

The effect of the environment on metal corrosion. The % EMC max represents the maximum amount of moisture that was present in hygroscopic collection materials. Because metallic corrosion is dependent on available moisture, the % EMC gives us an idea whether or not metallic objects (mainly ferrous metals) would corrode in such an environment.

Applies to:

Metals or materials with metal components.

Corrosion Metric	Interpretation
Max EMC ≤ 7.0	GOOD
7.1 ≤ Max EMC ≤ 10.5	OK
Max EMC > 10.5	RISK

Mold Risk

Measures:

The risk for growth of the xerophilic mold species on collection objects or in collection areas.

Applies to:

All organic materials (paper, textiles, plastics, dyes, leather, fur) or inorganic materials with organic films.

Mold Risk Metric	Interpretation
MRF ≤ 0.5	GOOD
MRF > 0.5	RISK

Note: There is no "OK" rating for mold risk. At a MRF of 0.5, conditions are appropriate for germination of spores. By alerting RISK of mold growth at germination, the user is aware of the potential of mold growth before any visible or vegetative mold will appear. This allows for time to react and prevent formation of vegetative mold.

Mechanical Damage

Measures:

Three aspects of moisture content that promote mechanical or physical damage:

1. Max % EMC: Is it too damp? Will paper curl? Will emulsions soften? Will wood warp?
2. Min % EMC: Is it too dry? Will paper become brittle? Will emulsions crack?
3. % DC: How great are the fluctuations between the most damp and the most dry? Has expansion and contraction - from absorption/de-sorption of water - put physical stress on the collection materials?

Applies to:

All organic materials (paper, textiles, plastics, dyes, leather, fur) or inorganic materials with organic films.

Mechanical Damage Metrics	Interpretation
Min EMC ≥ 5% AND Max EMC ≤ 12.5% AND %DC ≤ 0.5%	GOOD
Min EMC ≥ 5% AND Max EMC ≤ 12.5% AND 0.5% < %DC ≤ 1.5%	OK
Min EMC < 5% OR Max EMC > 12.5% OR %DC > 1.5%	RISK